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EFFECT OF ENVIRONMENTAL TEMPERATURE ON SWEAT ONSET DURING MOTION SICKNESS

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13. ABSTRACT

Since the sweat response is observed as part of some motion-sickness-rating procedures, it is useful to know if other variables such as environmental temperature can affect the response during vestibular stimulation. Eight young men were each exposed to the same vestibular stimulation on several occasions. On each occasion the run was carried out with a different environmental temperature. At a relatively high temperature the thermal stress caused a sweat response, and no vestibular stimulation was required. With lower environmental temperatures, a longer period of vestibular stimulation was required to evoke the sweat response. At a relatively low temperature no sweating was observed despite continuous vestibular stimulation and the development of severe nausea. The results indicate that environmental temperature can affect the sweat response during motion sickness and suggest the possible hazard of excessive fluid and electrolyte loss when both vestibular and thermal stress are present. By proper selection of environmental temperature, sweating can be induced before the onset of nausea. In this situation the sweat response could serve as a useful predictor of motion-sickness onset in the administration of adaptation schedules and in monitoring persons in the space-flight environment.

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SUMMARY PAGE

THE PROBLEM

It is known that the incidence and severity of motion sickness are not influenced by environmental temperature; however, the effect of environmental temperature on individual symptoms is not known. This study was carried out to determine the effect of environmental temperature on the onset of the sweat response during the elicitation of motion sickness by vestibular stimulation.

FINDINGS

As the environmental temperature was lowered, increased amounts of vestibular stimulation were required to evoke the sweat response. This effect was observed within definite limits. At a relatively high temperature the thermal stress was sufficient to evoke a sweat response, and no vestibular stimulation was required. Conversely, at a relatively low temperature sweating was not observed despite a long period of vestibular stimulation and the development of nausea. These temperature limits showed considerable variation from subject to subject.

RECOMMENDATIONS

Vehicular environments that subject the occupants to both thermal and vestibular stress (e.g., airplanes, ships, etc.) may cause early and excessive sweating. If the sweating is sustained for long periods of time, excessive levels of fluid and electrolyte loss and/or inadequate fluid load to the kidneys could result. It is recommended that, for such vehicles, adequate consideration be given to the following:

1. Facilities for replacement of fluid and electrolyte losses.

2. Adequate air conditioning to control the thermal environment.

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INTRODUCTION

Sweating is generally accepted as one of the cardinal signs of motion sickness and is often used in motion-sickness-rating procedures (2,3,11) to help establish end-points and severity levels. In the past it has been common practice to determine the onset and progression of sweating on the basis of observer and subject estimations. With the use of a more objective method for qualitative sweat determination (10), it is possible to demonstrate the effects of certain variables, such as environmental temperature, that might alter the sweat response.

Crampton (1) reported that during motion sickness, more sweating occurred at a temperature of 94°F than at 80°F. However, it is difficult to interpret the meaning of this observation from the motion-sickness point of view since at such high temperatures (especially 94°F), one would expect the majority of individuals to sweat because of thermal stress alone.

Hemingway (4) in his study on cold sweating during motion sickness tabulated a small amount of data that included both sweat rates and environmental temperature. Although he did not comment on the effects of environmental temperature, the data that he gave for seven subjects showed that lower temperatures were accompanied by lower sweat rates.

In a recent study (9) it was found that environmental temperature could alter the sweat response that occurs during motion sickness. In that study the sweat response from the dorsal hand was compared with that from the palm of the hand. Those experiments were carried out in an environmental chamber in which the room temperature could be selected. With two of the subjects, a sweat response was not evoked at a temperature of 75°F but was observed at 78°F. This suggested the possibility that environmental temperature could influence significantly the motion-sickness sweat response. Since in motion-sickness research it is not common practice to control or monitor environmental temperature (other than that obtained with conventional air-conditioning systems), an experimental procedure to demonstrate any temperature effects should be beneficial.

PROCEDURE

SUBJECTS

Eight young men ranging in age from 20 to 29 years served as subjects. All were vacationing college students who volunteered for the experiment. The subjects received generous remuneration for each run in which they participated. All subjects were in good health and showed no abnormalities on extensive medical and vestibular testing.

APPARATUS

Motion sickness was elicited by subject-induced side-to-side head movements while on a motor-driven chair rotating at constant velocity about a vertical axis. The headrest on the chair was equipped with lateral stops in order to keep the magnitude of the head movements constant. The subject wore a "head position indicator" which showed when the head was in the upright, right lateral, or left lateral position. This device consisted of a head band on which two mercury switches were mounted. One switch was turned on in each of the right and left lateral positions, providing signals of opposite polarity to the recorder.

Sweating was detected by two independent techniques. The skin resistance sensor (SRS) consists of two Beckman miniature skin electrodes and a Sanborn 350-12 GSR bridge as a constant current source. Current is passed in and out across the skin surface at the electrode sites. Changes in the voltage difference between the two electrodes reflect the skin resistance changes that occur during sweating. In the second technique an electrochemical sensor (ECS), which is described in detail elsewhere (10), is used. This sensor contains a $LiCl \cdot H_2O$-$AlCl_3$ sensing element and responds to the moisture content of air that is passed over the skin surface.

All runs were carried out in an environmental chamber in which the room temperature could be selected. The air conditioning in the chamber was turned off during the actual runs to eliminate any temperature cycling, which was a function of the temperature-control system. Room temperature was monitored by a thermistor probe mounted on the back of the rotating chair. Before and after each run, the thermistor reading was checked against a mercury thermometer mounted adjacent to the thermistor probe, and a relative humidity determination was made by a sling hygrometer.

METHOD

Each subject experienced a total of six to ten runs, with the runs being carried out on consecutive working days (i.e., weekends excluded). For five of the subjects a final run was carried out after a rest period that ranged from 3 to 27 days. For any one subject, each run was carried out at a different environmental temperature. The order of temperatures was random and different from subject to subject. Prior to their run on any particular day, subjects were required to refrain from physical exercise and preferably spent their time in an air-conditioned environment. Subjects arrived in the air-conditioned laboratory building 30 to 60 minutes before the experimental procedure and were then acclimatized in the environmental chamber for a minimum of 20 minutes at the particular room temperature for the run.

On all runs both the SRS and the ECS were placed on the dorsum of the right hand as illustrated in Figure 1. In a previous study (9) this area was shown to be an active sweat site during motion sickness.

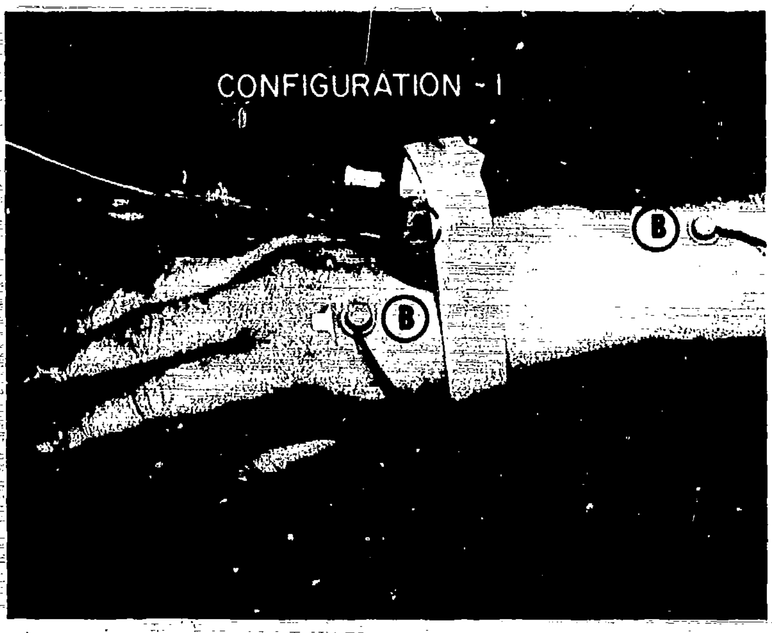

Figure 1

Placement of the sweat sensors on the dorsal hand. Electrochemical sensor (A); skin resistance sensor (B).

Rotation of the subject was always in the counterclockwise direction, and all runs were carried out at the same angular velocity for any one subject. The particular chair velocity selected for each individual was based upon an estimation of his sensitivity to motion sickness as determined from his previous experience in a rotating environment and from his personal history of motion sickness in various transport vehicles.

After acceleration (about $1°/sec^2$) to required velocity and a stabilization period of at least 1 minute, the subject commenced side-to-side head movements at the request of the experimenter. For purposes of standardizing stimulus exposure, a unit stimulus was defined by the following head movement sequence — vertical to right lateral to vertical to left lateral to vertical with a 1- to 2- second stop at each position. Although there were differences from subject to subject in the timing of the head movements, for any one individual the unit stimulus remained relatively constant for all runs.

On each run an attempt was made to establish endpoints for sweat and for nausea. The sweat endpoint was reached when both the SRS and the ECS indicated the onset of sweating. The nausea endpoint was reached when the subject first felt any stomach awareness.*

Three criteria were used to indicate successful completion of a run, namely: 1) establishment of both sweat and NI endpoints, 2) establishment of a sweat endpoint followed by at least twice as many head movement sequences without NI, and 3) establishment of an NI endpoint followed by either progression to NIV or at least twice as many head movement sequences without sweating. The significance of these last two criteria will become evident when the results are discussed.

RESULTS

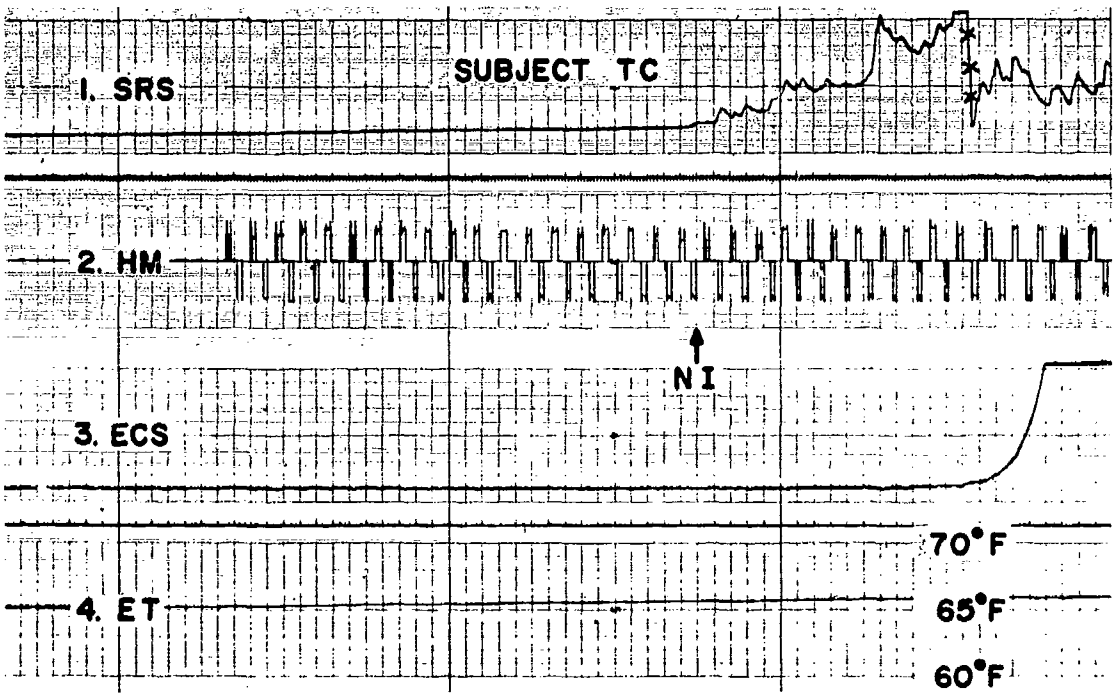

Figure 2

Typical response from the dorsal hand during motion sickness. 1) skin resistance sensor (SRS); 2) head movements (HM); 3) electrochemical sweat sensor (ECS); 4) environmental temperature (ET). NI (see text). Paper speed 1 mm/sec.

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*The nausea endpoint was an NI level measured on a five-point scale. NI denotes the first sensation in the stomach while NV denotes the feeling one has just prior to vomiting. NII, NIII, and NIV are nausea levels that the subject estimates to be equally spaced between NI and NV.

Figure 2 illustrates a typical response as recorded during an actual run. Trace 4 is a continuous recording of the environmental temperature in the chamber. For 92 per cent of the runs the temperature remained within ± 1.2°F of the average temperature for the run. Larger variations occurred during five runs. In these cases the room temperature differed markedly from that of the previous run, and the walls of the room, acting as a heat sink, tended to cause excessive temperature variation. The relative humidity varied linearly from 65 per cent at 82°F to 85 per cent at 63°F.

Trace 2 in Figure 2 shows the subject's head movements with an upward pen displacement indicating movement of the head to the right lateral position and downward pen displacement indicating movement of the head to the left lateral position. Traces 1 and 3 are continuous recordings of the SRS and ECS sweat responses, respectively. Generally, the onset of sweat detected by the SRS preceded that of the ECS by 5 to 30 seconds, although occasionally that order was reversed. The endpoint for sweat was arbitrarily defined as the average number of head sequences (in trace 2 one upward and one downward square waveform constitutes one head sequence or a unit stimulus) to the onset of the SRS and ECS responses. For example, in Figure 2 there are 19 head sequences to SRS sweating and 23 head sequences to ECS sweating. The sweat endpoint is the average of these two values, or 21 head sequences. A table of the results for each subject is given in the Appendix.

In Figure 3 a graph is plotted for each subject that illustrates the variation of the sweat endpoint with environmental temperature. In each graph the points were established by plotting the number of head sequences to reach the sweat endpoint against the room temperature for each run carried out on the subject. Only points that satisfied the three criteria for successful completion of a run (see method) were plotted in Figure 3. For example, six runs were carried out on subject L My but only two satisfied the aforementioned criteria. In each of the graphs of Figure 3 an additional point is plotted on the X-axis, which represents the temperature at which the thermal stress was sufficient to cause a sweat response and no head sequences were required.

With lower environmental temperatures, more head sequences were required to evoke the sweat response. This trend occurred within definite limits. At a relatively high temperature, sweating could be "turned on" with no vestibular stimulation, as indicated by the X-intercept in each graph. Conversely, at a relatively low temperature sweating could be "turned off" and was not observed despite a large number of head sequences (generally more than 60). The temperatures at which sweating was not seen are plotted in the graphs as open circles with vertical dashed lines extending upward.

The shape of the curves appears to have certain characteristics. At temperatures immediately below the "turn on" temperature, the number of head sequences to the sweat endpoint increases only gradually. However, at temperatures approaching the "turn off" temperature the curve rises sharply and becomes asymptotic to this value. The scatter of the intermediate points on the curves varied, being greatest for subjects LC and TC.

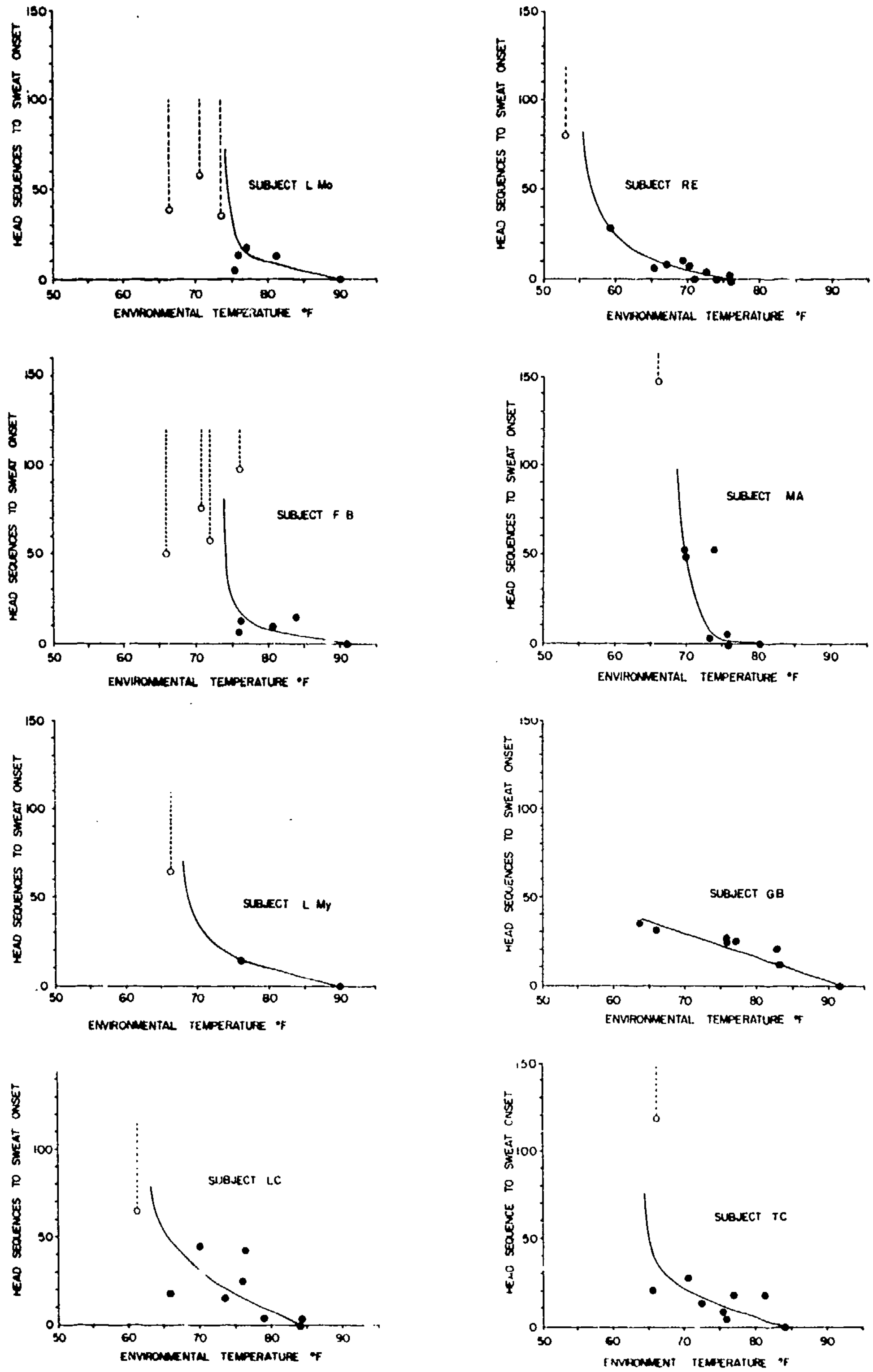

Figure 3

Variation of the sweat endpoint with environmental temperature for eight subjects. Open circles with vertical dashed lines indicate sweat endpoint not reached.

DISCUSSION

TEMPERATURE AND HUMIDITY EFFECTS

The results indicate that within a certain range, the environmental temperature does affect the motion-sickness sweat response. One could theorize as to the nature of the physiological mechanisms involved. Possibly the neural inputs resulting from thermal and vestibular stress summate to cause sufficient activity in the sweat effector system. A second possibility would be that vestibular stimulation lowers the threshold for thermal sweating. In effect, the "thermostat" is reset to a lower value. If this is the case, the existence of a sweat "turn off" temperature would indicate that there is a limit to the degree of threshold lowering. The existence of a sweat "turn on" temperature is to be expected and represents the normal situation in which sweating occurs solely on the basis of the thermal stress.

Of note is the variation of temperature ranges from subject to subject. For example, subject RE had "turn on" and "turn off" temperature limits of 76°F and 55°F, respectively, whereas these limits for subject FB were 90°F and 72°F. This would account for the so-called "nonsweater" in motion sickness. Such an individual probably has a high "turn off" temperature and would not sweat if the environmental temperature was below that value.

Since there was no humidity control on the environmental chamber, the relative humidity varied, depending on the temperature. The fact that the relative humidity was low at high temperatures, and vice versa, indicates that the actual moisture content of the air was relatively constant. It is unlikely that the relative humidity had much effect on the sweat response for two reasons. Firstly, the body has no direct method for sensing relative humidity, and any effect has to be an indirect one, acting as a result of the rate of heat loss due to evaporation at the skin surface. Secondly, the changes in sweating in relation to relative humidity were opposite to what one would normally expect. Higher values of relative humidity were associated with an increased latency of the sweat response. Normally when sweating occurs due to thermal stress, a high relative humidity is conducive to a more active sweat response since the evaporative process at the skin surface is less effective in body cooling.

HABITUATION EFFECTS

The scatter seen in the graphs of Figure 3 was not unexpected since subjects were exposed on a daily basis, and habituation* as well as temperature could alter

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*Habituation is defined as the "protection" gained by repeated exposure to a stimulus. In the case of the vestibular system, this is illustrated by the increased resistance to motion sickness resulting from daily exposure to appropriate vestibular stimulation.

the endpoint. The habituation effects shown in the scattergraphs can be eliminated if the ratio of head sequences to the sweat endpoint divided by head sequences to NI (sweat/NI ratio) is plotted against the environmental temperature. This is true only if the following three assumptions are true:

1. The number of head sequences to NI is not affected by environmental temperature.

2. For any one individual, the NI endpoint represents a constant level of motion-sickness intensity.

3. With habituation the change in the sweat endpoint is proportional to the change in the NI endpoint. In other words, despite habituation the sweat/NI ratio is a constant.

The first assumption requires that environmental temperature does not affect appreciably the NI endpoint. Other authors (1,5,6-8) have reported that environmental temperature does not affect the incidence of motion sickness in group studies or the susceptibility to motion sickness of individual subjects. In Figure 4 the number of head sequences to reach NI is plotted against environmental temperature. Note that there is no recognizable trend to indicate an influence of environmental temperature on the NI endpoint. This fact would support the validity of the assumption.

The second assumption implies that taking an individual to the NI endpoint on different runs is equivalent to taking him to the same stage of his motion-sickness syndrome. In the light of the first assumption, the effects of habituation should be evident in a plot of the number of head sequences to NI against the run number. Such a plot for each subject is illustrated in Figure 5. All runs were carried out on consecutive days except during the periods denoted by the shaded bars. These represent "no-run" periods with the number of days involved shown just above the bar. The points plotted as open circles and joined by dotted lines signify that the head sequences were carried out without reaching a positive NI endpoint. Habituation effects are readily apparent. For example, with subject GB considerably more head sequences were made on runs 2, 3, and 4 than on run 1. Between runs 4 and 5, there was a 2-day weekend, during which time no runs were carried out. Loss of habituation was demonstrated by the fact that the number of head sequences to NI on run 5 dropped almost to the level of run 1. On run 6 habituation was again evident, and loss of habituation again occurred during the "no-run" period between runs 7 and 8.

Subjects L Mo and RE are of interest in that they showed very little evidence of habituation. Since habituation was not a factor, both subjects have a minimum of scatter in their sweat onset versus temperature curves of Figure 3. The remaining six subjects showed variable degrees of habituation. Subjects FB and MA showed major effects on only a few runs. Since most runs were not influenced by habituation, there is also a minimum of scatter in their curves of Figure 3. In the case of subject L My, habituation was so effective that on runs 2, 3, 5, and 6 neither a sweat nor an NI endpoint was obtained. As a result only the data from runs 1 and 4 could be plotted in Figure 3.

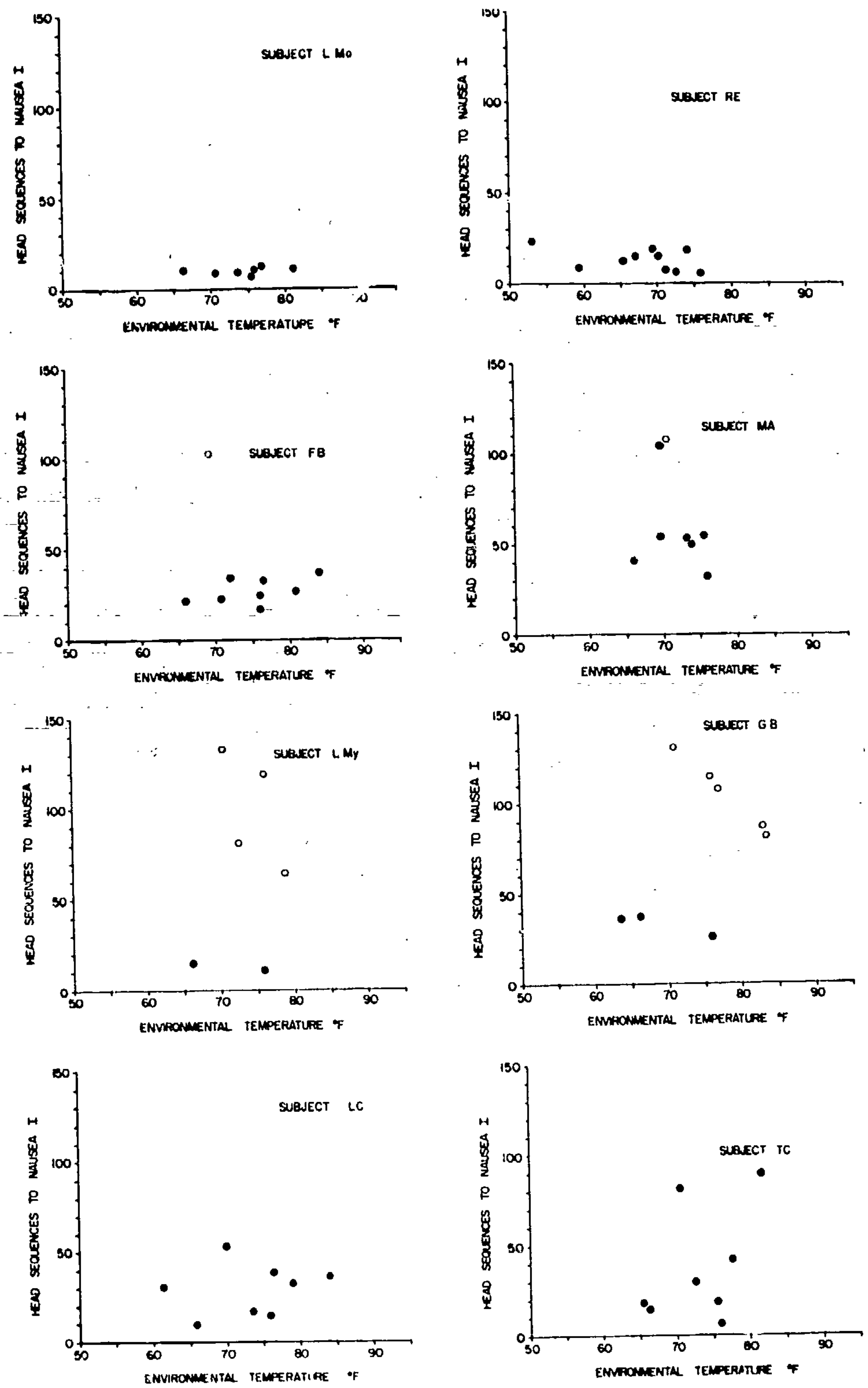

Figure 4

Graphical presentation for each subject to show lack of influence of environmental temperature on the NI endpoint. Open circles indicate NI not reached.

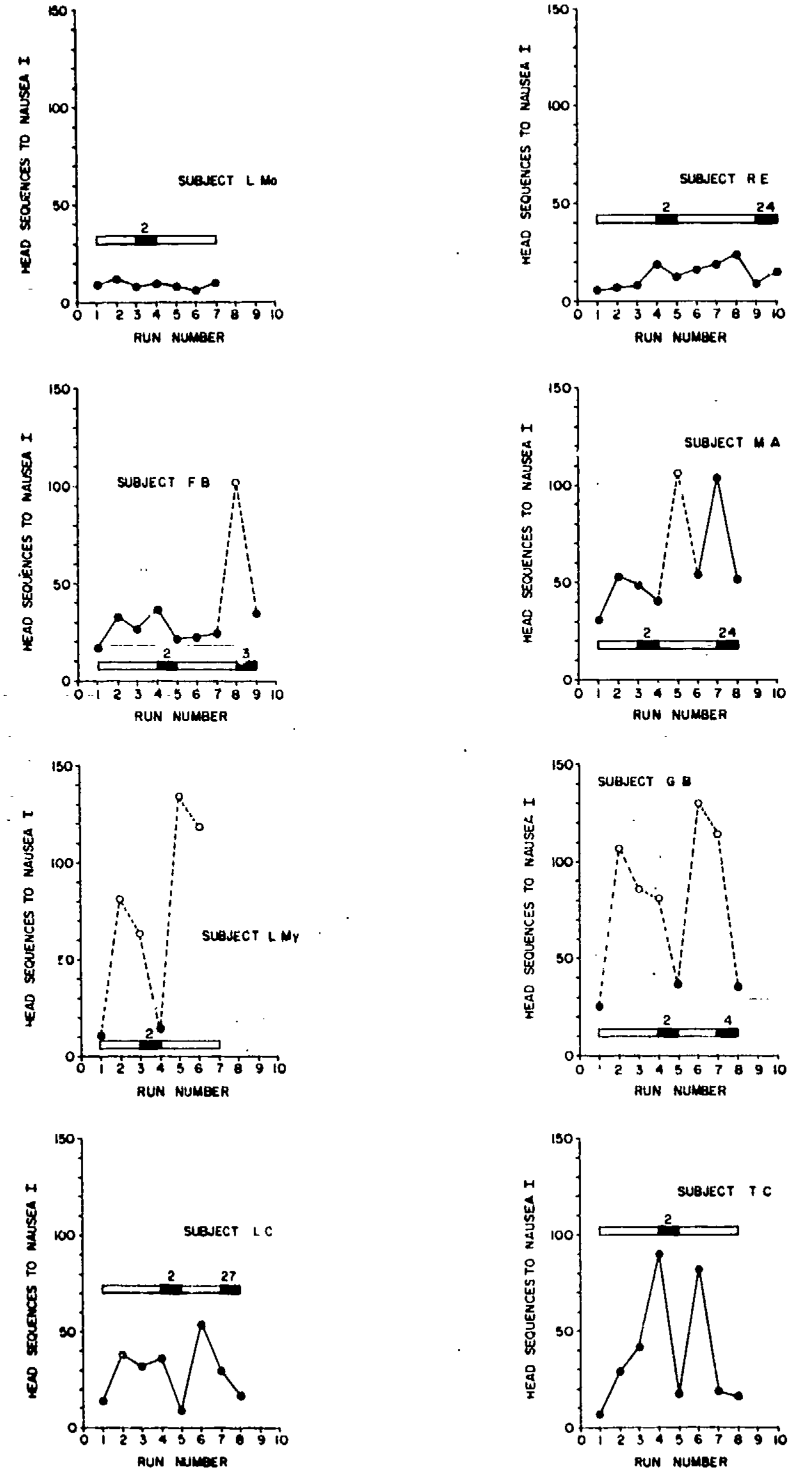

Figure 5

Habituation effects as illustrated by the variation of Nausea I (NI) endpoint with run number. Open bars denote runs on consecutive days. Shaded bars denote rest periods (number of rest days signified above bar). Open circles joined by dashed lines indicate NI not reached.

The fact that habituation effects can be seen using the NI endpoint would support the validity of its use as an indicator of the level of motion-sickness intensity.

The third assumption requires that habituation does not affect the sweat/NI ratio. For example, if run 1 requires 10 and 5 head sequences to the NI and sweat endpoints, respectively, and run 2 requires 20 head sequences to NI, then on run 2 it will take 10 head sequences to the onset of sweating.

If all three assumptions are correct, then a plot of the sweat/NI ratio against environmental temperature will eliminate habituation effects but still demonstrate how sweat onset varies with temperature. These plots are illustrated in Figure 6. The open points supporting the dashed vertical lines indicate that an NI endpoint was reached but sweating did not occur despite a large number of head sequences. Thus the sweat/NI ratio must lie somewhere on the vertical dashed line. In the case of subject GB, the open points at the higher temperatures indicate that a sweat endpoint was reached but NI did not occur despite a large number of head sequences. The actual point thus lies slightly closer to the X-axis. The fact that meaningful points could be obtained, although only one endpoint was reached, was the basis for the second and third criteria to indicate successful completion of a run (see method).

The curves all retain the characteristic shape seen previously in Figure 3. In the case of subject GB, there is possibly a slight improvement in the shape of the curve to bring it more in line with the others. Unfortunately, a "turn off" temperature was not established in this subject to define the lower limit of the curve. Of note is the reduced amount of scatter in the case of subjects LC and TC. Both showed significant habituation effects (Figure 5).

The remaining scatter in the curves of Figure 6 can be accounted for on the basis of adaptation.* This was obvious in a few extreme cases in which one could observe the onset of sweating followed by recovery. At some later time sweating again occurred and the NI endpoint was reached. In such a situation adaptation caused recovery of the sweat response and undoubtedly would delay the NI endpoint as well. If the sweat/NI ratio is calculated on the basis of the initial sweat response, an erroneous value for the ratio results. Although such extreme cases of adaptation were rare, lesser degrees of adaptation would be present and could cause some scattering of the points.

PRACTICAL CONSIDERATIONS

From the results it is evident that with higher temperatures, motion-sickness sweating onsets with lesser amounts of vestibular stimulation. It is possible that vestibular

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*Adaptation is defined as the decline of a response during continuous exposure to a stimulus. The outstanding feature of adaptation is the fact that it is a dynamic phenomenon and occurs only in response to a stimulus change and only while the stimulus change is applied.

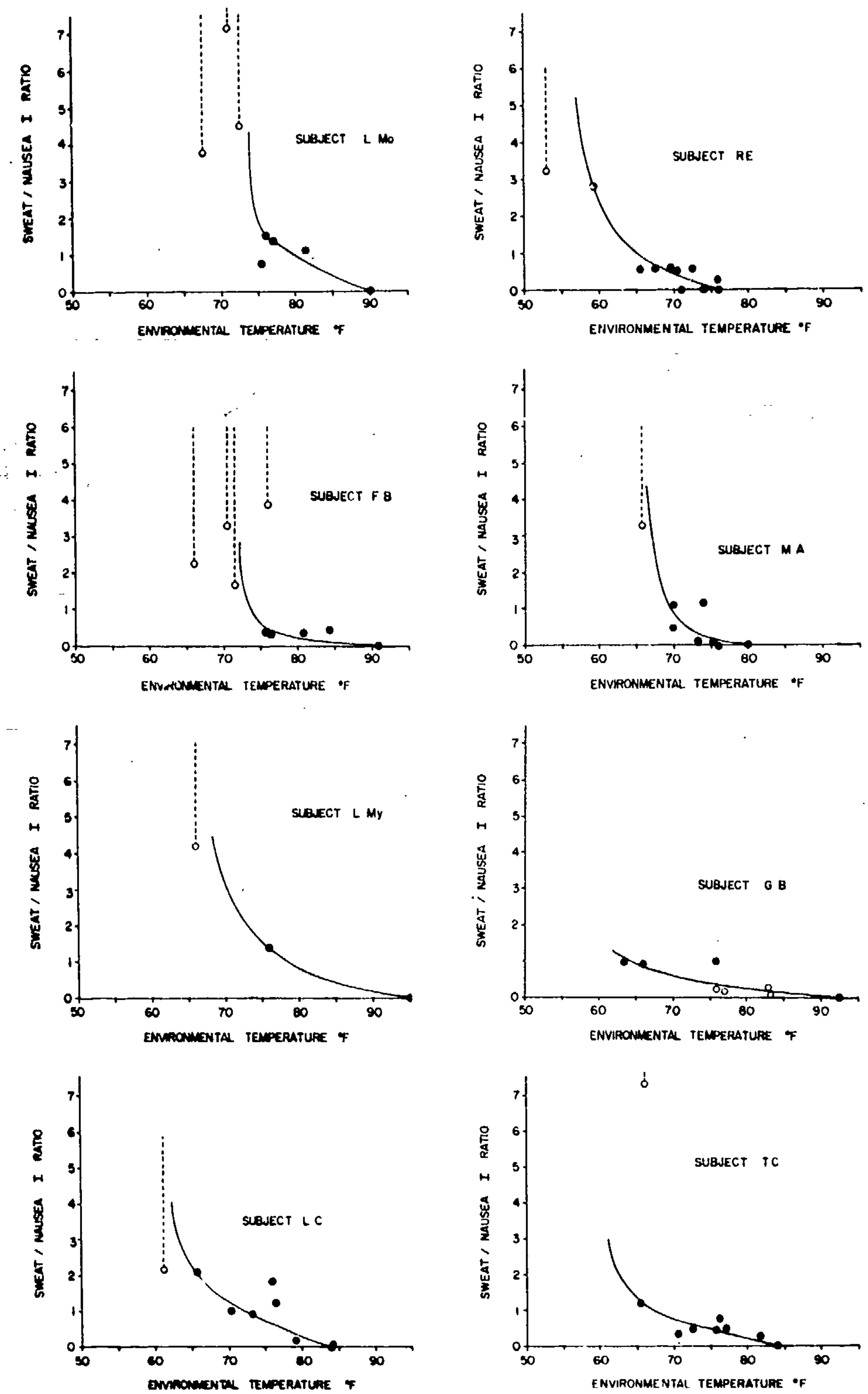

Figure 6

Variation of sweat/nausea I ratio with environmental temperature for eight subjects. Open circles with vertical dashed lines indicate sweat endpoint not reached. Other open circles indicate nausea I endpoint not reached.

stress acting in conjunction with thermal stress could cause excessive levels of body-fluid loss in the form of sweat. Since thermal stress is present in many of the vehicular environments in which motion sickness is a problem, the increased possibility of body-fluid loss if the sweating is sustained for long periods of time and thus the danger of dehydration and reduced fluid load to the kidneys should be recognized. This is especially important in vehicles in which there is no or limited facility for salt and water replacement for the individuals on board.

From the curves of Figure 6, it is evident that, for any subject, a temperature can be selected that will result in a sweat/NI ratio of less than one. Use of such a temperature means that sweating will always occur prior to NI. Thus the sweat response becomes an indicator of motion-sickness onset and a predictor of NI and other more discomforting symptomatology.

With the above in mind, sweating could be used to monitor the progress of an adaptation schedule. The adaptation schedule could be carried out with a minimum of discomfort to the individual since the onset of motion sickness could be detected without inducing nausea. It is also probable that the schedule time could be reduced to a minimum.

In the area of space flight and other environments with limited access, the sweat response could be used to detect the early onset of motion sickness. Ground control might possibly detect the onset of motion sickness before the astronaut is aware of it himself. This would allow for early assessment of the situation with respect to restricting activity and the administration of antimotion sickness drugs.

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APPENDIX A

Table of Results*

Subj.	Run No.	Envir. Temp. deg F	HMS To Sweat	HMS To NI	Sweat/NI
	1	76.0	14	9	1.6
	2	77.0	17	12	1.4
	3	73.5	36	8	4.5
L Mo	4	66.5	39	10	3.9
	5	71.0	58	8	7.2
	6	75.5	5.0	6	0.8
	7	81.0	12	10	1.2
	1	76.0	6.5	17	0.38
	2	76.5	12.5	33	0.38
	3	81.0	9.5	27	0.35
	4	84.0	16	37	0.43
FB	5	66.0	50	22	2.3
	6	71.0	76	23	3.3
	7	76.0	98	25	3.9
	8	69.0	102	102	— +
	9	72.0	58	34	1.7
	1	76.0	15	11	1.4
	2	72.5	81	81	— +
L My	3	79.0	64	64	— +
	4	66.0	64	15	4.2
	5	70.5	133	133	— +
	6	76.0	119	119	— +
	1	76.0	25	14	1.8
	2	76.5	46	38	1.2
	3	79.0	4.5	32	0.14
LC	4	84.0	3.0	36	0.08
	5	66.0	18	9.0	2.0
	6	70.0	46	53	0.87
	7	61.5	65	30	2.2
	8	73.5	15	17	0.88

Subj.	Run No.	Envir. Temp. deg F	HMS To Sweat	HMS To NI	Sweat/NI
	1	76.0	1.5	6.0	0.25
	2	72.5	4.0	7.0	0.57
	3	71.0	0	8.0	0
	4	69.5	10	19	0.53
	5	65.5	7.0	13	0.54
RE	6	70.0	8.0	16	0.50
	7	74.0	0	19	0
	8	53.0	79	24	3.3
	9	59.0	26	9.0	2.9
	10	67.0	8.5	15	0.57
	1	76.0	0	31	0
	2	70.0	52	53	1.0
	3	74.0	53	49	1.1
	4	66.0	146	41	3.6
MA	5	70.0	106	106	— +
	6	75.5	5.0	54	0.09
	7	70.0	50	104	0.48
	8	73.0	3.0	52	0.06
	1	76.0	25	26	1.0
	2	77.0	25	107	0.23
	3	83.0	22	86	0.26
	4	83.0	12	81	0.15
GB	5	66.0	33	37	0.91
	6	71.0	130	130	— +
	7	76.0	26	114	0.23
	8	63.5	36	36	1.0
	1	76.0	5.0	7.0	0.72
	2	72.5	14	29	0.48
	3	77.0	18	42	0.43
TC	4	81.5	18	90	0.20
	5	65.5	21	18	1.2
	6	70.5	28	82	0.34
	7	75.5	8.0	19	0.42
	8	66.0	119	16	7.4

*Footnotes:

HMS - Head movement sequences (1 upward plus 1 downward head movement).

NI - Nausea I (see text).

Circled values mean head movement sequences were made but endpoint was not reached. All such values are plotted in the graphs as open circles.

+ - Criteria for successful completion of a run (see method) not satisfied.